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Far-infrared spontaneous intraband emission from laser structures with quantum dots and quantum wells

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Abstract. Spontaneous far-infrared radiation ($\lambda \simeq 10\dots20$ μm) from laser structures with vertical coupled InGaAs/AlGaAs quantum dots (QD) connected with intrasubband hole and electron transitions between levels of size quantization in QD as well as with transitions from continuum to QD levels was found. Far-infrared radiation is observed only under simultaneous generation of short wavelength interband radiation ($\lambda \simeq 0.94$ μm) and has a current threshold just as short wavelength radiation. Spontaneous far-infrared radiation is observed also from laser InGaAs/GaAs structures with quantum wells (QW). Intensity of this radiation is about of order less then intensity of radiation from structures with quantum dots and has no current threshold.

Introduction

Intersubband optical transitions of carriers in QW have been investigated in detail, the infrared detectors, modulators and lasers have been developed (see, for example [1, 2]). A study of interlevel carrier transitions in quantum dots opens the new prospects in designing the active devices for far infrared (FIR) region ($\lambda > 10$ μm). A light absorption due to electron transitions from bound states into continuum as well as due to hole transition between levels in QD have been investigated recently [3].

In this work the spontaneous FIR emission as a result of electron transitions from continuum to QD levels as well as of interlevel transitions in QD was detected. This radiation is conditioned by synchronous generation of radiation, which is caused by electron transitions between ground levels of electrons and holes ($h\nu \simeq \varepsilon_g$). The latter provides a depletion of these levels at high current injection of electron-hole pairs in QD heterolaser. The fact, that such a spontaneous radiation have been observed, may be considered as the first step of development of the FIR laser based on interlevel carrier transitions in QD.

1 The samples and technique of experiments

The laser structures with vertical-coupled QD described in [4] were used. The active region of such a laser consists of the $Al_{0.5}Ga_{0.5}As$ layers with self-organized $In_{0.5}Ga_{0.5}As$ quantum dots, the number of layers is 10. Stimulated radiation corresponds to near infrared (NIR) region with wavelength about 0.94 μm at 300 K. The silicon photodiode was used for registration of this radiation. The measurements were carried out with current pulse having duration about 200 ns.

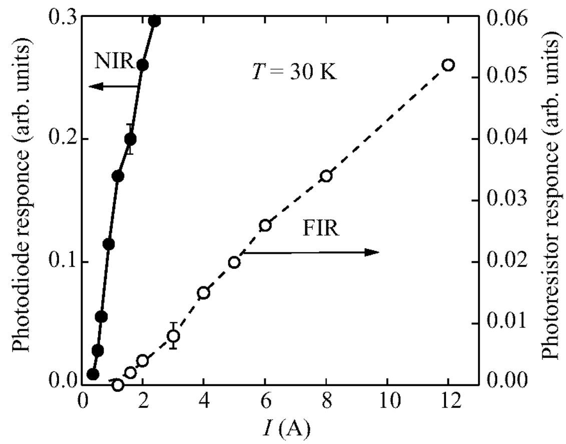

Fig 1. Intensity of NIR and FIR radiation from QD structure.

To find FIR radiation from these structures the Ge⟨Cu⟩ and Si⟨B⟩ photodetectors having the sensibility in spectral region $\lambda = 5\ldots29$ μm at $T \simeq 30$ K were used. The Ge and InSb filters placed before photodetectors cut off NIR ($\lambda = 0.94$ μm) radiation, the spectral data in the long-wave range were determined by means of set of BaF_2, NaCl and KBr filters. The NIR and FIR radiations were investigated simultaneously.

Also spontaneous FIR emission from laser $In_{0.2}Ga_{0.8}As$/GaAs quantum well structures have been investigated.

2 Results and discussion

Fig.1 represents the typical optical-current dependencies of both stimulated NIR and spontaneous FIR emission from QD laser structures. Spectral range of FIR radiation ($10\ldots20$ μm) was established with the help of filters. It should be noted that dependence of intensity of spontaneous FIR radiation on laser current has a threshold closed to the threshold current of generation of stimulated NIR emission. The latter is of 0.33 A at the low temperatures that is one half of the same at the room temperature. So, FIR radiation may be registered only at the same time with generation of NIR one.

The same investigations have also been carried out in $In_{0.2}Ga_{0.8}As$/GaAs QW laser structures with threshold current of generation of NIR radiation about 0.25 A. Spontaneous FIR emission was found out in these structures too. In this case intensity of radiation was about tenth path of that in QD structures and had no threshold dependency on an electric current.

Our qualitative explanations of phenomena observed are as follows. First let us discuss the conditions under which spontaneous FIR emission from QD laser structures is possible. It may be assumed that quantum level structure in QD used is like to that described in [5] with characteristic linear sizes of the base of pyramid being about 10…12 nm. Such the structures have only one electron level $|000\rangle$ (in our structures two electron levels can exist), and four hole levels: $|000\rangle$, $|100\rangle$, $|001\rangle$ and $|110\rangle$. Under electron (hole) injection into AlGaAs layer an electron (hole) capture is executed by

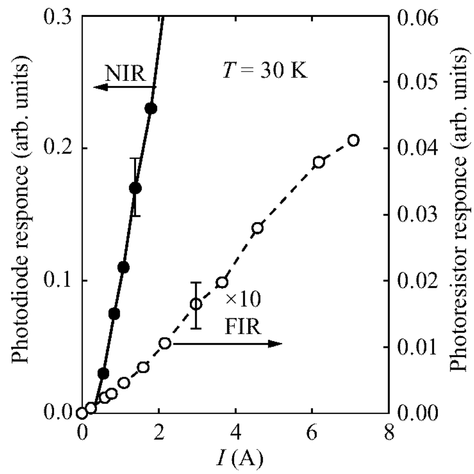

Fig 2. Intensity of NIR and FIR radiation from QW structure.

the states in the wetting layer for some picosecond [6, 7] with its following transitions to the electron (hole) QD level. The hole inter-level transitions are also possible. In accordance with [6] a transition time between excited and ground levels is about 40 ps.

At threshold current I_{th} the ground electron (hole) states in QD are filled and optical transition from excited QD levels to ground ones are impossible.

At pumping current above I_{th} the stimulated NIR emission origins, the corresponding interband transitions deplete the ground electron and hole states in QD and spontaneous FIR emission is started. The intensity of this radiation is proportional to the number of carriers in excited states N_{ex} and probability the lowest levels to be desolated. N_{ex} is linear current function and desolation probability increases with intensity of stimulated NIR radiation.

A current increase involves into generation more and more QD with different sizes. Owing to above mentioned reasons the FIR radiation intensity may increase faster in compare with linear law. It is confirmed with experimental results at $I > I_{th}$: $J^{\nu}_{FIR} \propto I^2$ (see Fig. 1). A further increase of current leads to linearization of the dependence. It is, probably, connected with hole (electron) ejection from excited states by intense stimulated radiation and increasing effect of Auger processes [8].

We observed also spontaneous FIR radiation from $In_{0.2}Ga_{0.8}As/GaAs$ QW structures. The carrier number in excited states (i.e. in upper subbands) is proportional to a current through a structure. Ground subbands have always unoccupied states, the holes (or electrons) pass into them. That is why the intensity of FIR radiation is proportional to a current: $J^{\nu}_{FIR} \propto I$ and has no threshold (see Fig. 2). It should be noted that carrier life time in QW excited states is of order of picosecond, it is less than one tenth of life time in QD. Owing to small life time the intensity of FIR radiation in QW was smaller than that for QD structures.

Thus, our results give a hope to receive population inversion for electrons and holes in FIR range under interband NIR generation and to create new active devices, for instance, FIR laser on the base of interlevel transitions of carriers in QD.

Acknowledgments

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